U.S. Bureau of Ordnance (Navy dept.)

U. S. NAVY BUREAU OF ORDNANCE IN WORLD WAR II

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BUREAU OF ORDNANCE
DEPARTMENT OF THE NAVY

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Chapter 1

THE BUREAU AND ITS WORK

THE contribution of sea power to victory in World War II is already familiar, at least in its broad outlines. Starting with the rebuilding of a fleet after Pearl Harbor, it is the story of ships and men, of task forces and individual heroism. Less familiar is the role of naval ordnance, the broad category of defensive and offensive weapons that make the difference between a mere seagoing vessel and a real man-of-war. United States armament was not invariably superior to that of the enemy, but it was generally better; in some cases it was so markedly superior in quantity and quality that the degree of its superiority proved the margin of victory over a powerful enemy.

Modern naval ordnance includes everything that is thrown at the enemy, the weapons for throwing them, the instruments for insuring their accuracy, and many of the protective devices that parry the enemy's blows. The design, production, issue, and maintenance of that armament is the responsibility of the Bureau of Ordnance, one of the material Bureaus in the Navy Department. Where its field was once confined to the surface of the sea, it now extends to hundreds of feet below and thousands of feet above the ocean.

Founded in 1842, the Bureau supplied ordnance for 4 wars prior to World War II, but the activity of the whole first century of its existence was dwarfed by comparison with the 4 years that followed. Even World War I, with its ordnance expenditures of approximately $1 billion, provided no adequate comparision with the $13.8 billion program required little more than two decades later. Moreover, the growth occasioned by that war was of small value when a new demand for sea power arose after 20 years of peace. The United States soon reduced naval appropriations to the prewar level, and ordnance activity became largely a matter of maintaining the armament on the active fleet. Even that part of the Bureau's mission became less of a task after the United States took a leading part in the disarmament programs after World War I. The Washington Conference of 1922 had disastrous results for the United States Navy. Two hundred thirty-six ships, some recently completed and others still under construc-

tion, were scrapped or towed to sea and sunk, offering the Navy little for its loss but a few hours target practice.

Even that essential became a curtailed luxury in the following years, as a lack of interest in naval power forced the Bureau to operate with an economical but crippling budget. By 1930 the mission of lending punch to the ships at sea had to be accomplished by a Bureau force of only 22 officers and 64 civilians spreading an appropriation of $31,092,020 over the wide range of ordnance activities. While every effort was made to continue the development of new and improved weapons, little but maintenance of the existing force was possible. The shore establishment through which the Bureau fulfilled much of its mission was reduced to a bare minimum—a move permitted by the low workload of the Bureau and dictated by budgets which could not stand the overhead costs of maintaining a sizable shore establishment.

The process of retrenchment came to a stop in 1933, just when Hitler was preparing to destroy the Weimar Republic. In the years that followed, the naval picture in the United States changed perceptibly. Appropriations remained low, but Navy funds were supplemented by money made available through the National Industrial Recovery Act and the Public Works Administration. With the increased funds, the Bureau of Ordnance began a gradual and orderly expansion of its activities. Quantitatively, ordnance procurement increased about 2½ times; total appropriations rose from the 1923–32 average of $23,300,000 annually to a yearly average of $59,500,000 during the period from 1933–39. The dollars spent during this period of expansion can easily be envisioned in terms of weapons for battleships 55 to 60, destroyers 409 to 436, and submarines 188 to 203. To the extent that appropriations were used for new personnel, the significant increases took place at the four ordnance shore establishments actually engaged in production—the Naval Gun Factory, Washington, D. C., the Naval Powder Factory, Indian Head, Md., the Naval Torpedo Station, Newport, R. I., and the Naval Ordnance Plant, Baldwin, N. Y. Procurement was drawn from three main sources—the Navy's own, Army arsenals with a surplus capacity, and from private manufacturers. While the latter originally claimed the smallest share of the money spent, a trend developed in the opposite direction. By 1939 contracts with private firms exceeded the cost of government production. Within that broad trend, another became apparent: the tendency to decrease dependence on eastern firms and spread naval production over the Nation.

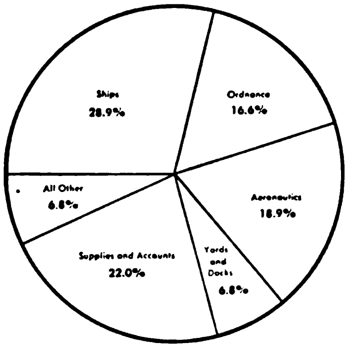
NAVY WAR PROGRAM BY BUREAU

INCLUDING LEND LEASE

JULY 1, 1940—AUGUST 31, 1945

PERCENTAGE DISTRIBUTION OF AUTHORIZATIONS

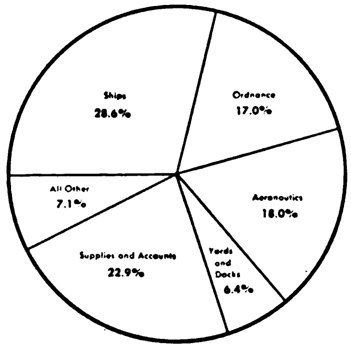
TOTAL AUTHORIZATIONS—$139.0 BILLION



Ships	$40.2 Billion
Ordnance	23.1
Aeronautics	26.1
Yards and Docks	9.5
Supplies and Accounts	30.6
All Other	9.5

PERCENTAGE DISTRIBUTION OF APPROPRIATIONS

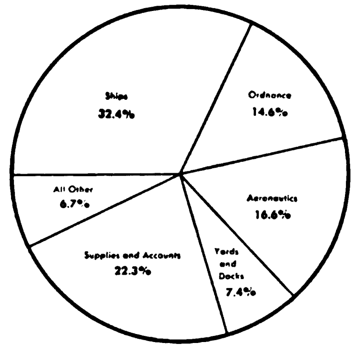
TOTAL APPROPRIATIONS—$133.0 BILLION



Ships	$38.0 Billion
Ordnance	22.6
Aeronautics	23.9
Yards and Docks	8.5
Supplies and Accounts	30.5
All Other	9.5

PERCENTAGE DISTRIBUTION OF EXPENDITURES

TOTAL EXPENDITURES—$94.5 BILLION



Ships	$30.6 Billion
Ordnance	13.8
Aeronautics	15.7
Yards and Docks	7.0
Supplies and Accounts	21.1
All Other	6.3

While the change in emphasis from maintenance to expanding production indicated the direction of future Bureau growth, the problems to be solved and the programs followed were subject to many changes in the years between 1939 and 1945. As war broke out in Europe and the Nation became more conscious of the need for preparedness, the expansion program accelerated until ordnance production rates prior to our entry in the war were in excess of anything witnessed during World War I. But as great a growth as this expansion represented, the times demanded more. On September 8, 1939, a declaration of limited emergency was made by President Roosevelt, followed on November 4 by congressional enactment of the "cash and carry" revision of the Neutrality Act. This revision permitted those nations with access to the United States to tap our supplies, and the results were a stimulus to the Nation's war production. As beneficial as that ultimately proved to our own services, the effect was competition and higher prices for war material.

Industrial mobilization planning had been predicated on an M-day, when overall control of facilities and materials would be legally possible. The substitution of a gradually deepening emergency for that original plan had real advantages in terms of a slow growth of productive ability, but not until the Lend-Lease Act of March 11, 1941, were the services in a position to take advantage of the war abroad by giving direction to the expansion of facilities for war production and by controlling the allocation of scarce items. Meanwhile, the war in Europe had taken a critical turn when the Nazis overran Denmark, Norway, France, and the Low Countries in the spring of 1940. On June 14, 1940, Congress answered the German challenge with an 11 percent raise in the shipbuilding program, followed within a month by the "two ocean" or 70 percent increase.

That congressional action launched the Bureau of Ordnance on a new program. A shortage of funds had been the perennial problem; now expansion of facilities had to absorb the energy and much of the funds available to the Bureau, for its task was essentially that of building a war production machine in peacetime. The general increase in ordnance procurement prior to 1939 was not sufficient to occasion a general facilities expansion program over the Nation. The facilities and the knowledge of ordnance manufacturing were hopelessly inadequate for anticipated needs, and a shortage of machine tools, intensified by the "flatness" of the machine tool industry, threatened to cripple the effort at the outset. Even before United States entry into the war, the demands of

lend-lease and a growing fleet at home outstripped the production sources available to the Bureau. Relief came from efforts in two different directions—the creation of new manufacturing plants within the Ordnance Shore Establishment, and the harnessing of private industry to the defense effort.

Naval Ordnance Plants were not newcomers to armament manufacture. Three such plants, located at Dayton, Ohio, South Charleston, W. Va., and Baldwin, N. Y., were commissioned during World War I. The last two remained under Navy ownership and made important contributions again in World War II. When the creation of additional plants became an obvious requirement, Congress responded in July 1940, with an initial authorization of $50,000,000 for the project. For its part, the Bureau surveyed over 200 sites which seemed to offer the advantages of inland location, adequate labor, and good transportation, then recommended 5 locations for construction. At each of these—Louisville, Ky.; Macon, Ga.; Indianapolis, Ind.; Canton, Ohio; and Center Line, Mich.—a Naval Ordnance Plant was erected. These facilities were bolstered early in 1942 by the construction of additional NOP's at Forest Park, Ill.; St. Louis, Mo.; and Pocatello, Idaho. The total number of new facilities reached 9 when a Milledgeville adjunct of the Macon plant was given separate status as an independent plant, then climbed to 10 when a Navy financed plant at York, Pa., was taken over and designated a NOP. The cost of the 10 new NOP's exceeded $150,000,000.

The operation of the facilities was an interesting compromise between private enterprise and a public venture. Ownership was entirely in government hands, but management was exercised by private contractors who operated the plants for costs plus a fixed fee. The system was applied to all of the NOP's except Pocatello; in every case but one, the experiment worked well. Aside from making industrial facilities available, Naval Ordnance Plants offered other advantages: production could be shifted quickly from one weapon to another without the delaying restrictions imposed by conventional contract procedures, thus permitting the kind of productive flexibility that the everchanging tactics of war demanded; by allowing exact calculations of cost, the production at NOP's aided the Bureau in its determination of fair prices in negotiations with private manufacturers.

Complementing the work of the Naval Ordnance Plants and the other manufacturing facilities were the rest of the ordnance field establishments—magazines, ammunition depots, laboratories, test

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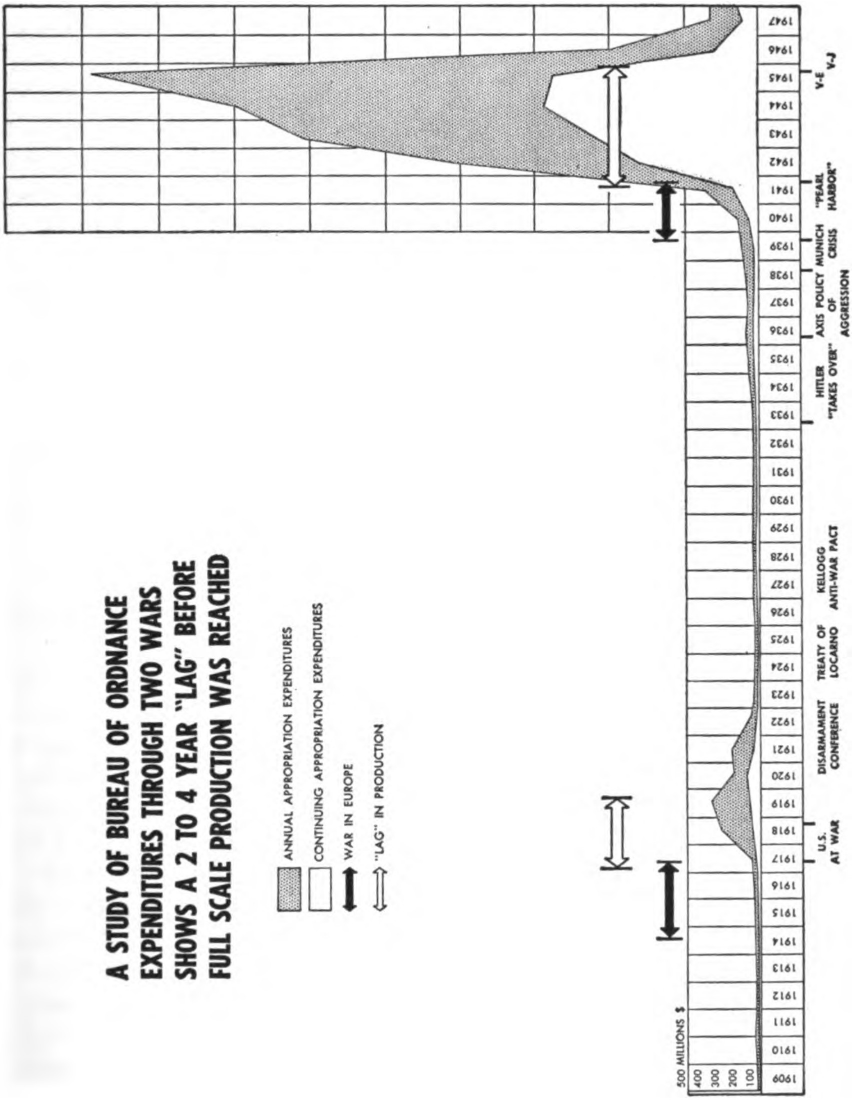
stations, and a variety of other facilities devoted to some special ordnance task. While their role was not primarily productive, they performed supplementary roles such as loading, assembly, and handling—jobs which were all important in a field where procurement was normally confined to components rather than a finished product. In some cases, they actually entered production when the scope of procurement was limited or urgency demanded "crash" programs that gave manufacturing a higher priority than the primary mission of the establishment involved. The shore establishment continued its steady growth during the war until it reached a capital value of one and a quarter billion dollars.

The expansion of Navy facilities under the Bureau of Ordnance was an important approach to the vital problem of assuring an adequate supply of naval armament, but the need to exploit the enormous productive capacity of American industry was apparent even before the demands of war revealed the inadequacy of peacetime plans. Prior to Pearl Harbor, however, there were many obstacles to tapping the Nation's commercial sources. Profits were high, the world market for consumer and heavy goods was absorbing production, and the incentive of patriotism was still unaroused. Naturally, but unfortunately, private capital was hesitant to invest in costly expansion for production of problematical duration, especially since much of the equipment necessary for the production of armor and armament had almost no commercial value. That hesitancy to invest was intensified by the profit-limiting features of the Vinson-Trammell Act, originally designed to protect the Government from excessive costs on naval contracts, but ultimately serving to produce timid manufacturers. On the shoulders of the Bureau of Ordnance fell the task of seeking government action which would open the door to private capital, while using public funds to speed that essential work.

Facility contracts involving vast sums of money followed in rapid succession; before the attack on Pearl Harbor funds to the extent of a billion and a half dollars were involved and the Bureau of Ordnance was administering the expansion of many manufacturing plants and imparting the knowledge of ordnance manufacture to the new participants—a complex and expensive program which involved supplying and keeping up to date the millions of blueprints required, the inauguration of training programs for management and labor in both government and private plants, and the establishment of an adequate inspection system to guarantee the requisite quality of ordnance products. Bureau prime contractors at the end of 1941 totaled 2381 firms, plus approximately 5000 sub-


A STUDY OF BUREAU OF ORDNANCE
EXPENDITURES THROUGH TWO WARS
SHOWS A 2 TO 4 YEAR "LAG" BEFORE
FULL SCALE PRODUCTION WAS REACHED
ANNUAL APPROPRIATION EXPENDITURES
CONTINUING APPROPRIATION EXPENDITURES
WAR IN EUROPE
"LAG" IN PRODUCTION
500 MILLIONS $
400
300
200
100
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U.S. AT WAR
DISARMAMENT CONFERENCE
TREATY OF LOCARNO
KELLOGG ANTI-WAR PACT
HITLER "TAKES OVER"
AXIS POLICY OF AGGRESSION
MUNICH CRISIS
"PEARL HARBOR"
V-E
V-J

contractors who furnished parts for assembly. Because of the experience and success of the Bureau in its facilities expansion program, the heavy forging procurement for the Bureau of Ships and the Maritime Commission was delegated to Ordnance.

Even though this initial emphasis on facilities expansion left ordnance production in relatively low gear when the United States was forced to enter World War II, Bureau foresight had prepared the way for a real wartime program of procurement. While no large stock of war materials could be shown for the money involved in the expansion program, the latent potential of the Nation was much closer to realization than had been true at the beginning of the emergency. That the investment produced good returns is shown by the fact that despite repeated accelerations of the shipbuilding program, vessels were never delayed for the lack of ordnance material. Nor was that due even in part to a time lag that might give ordnance an edge over shipbuilders. Defensive ordnance in the form of armor was tailored for each individual ship and worked into its structure at an early stage of construction. Despite the disappearance of our armor industry after the 1922 disarmament conference, the expense of the equipment needed for its manufacture, and the reluctance of the United States steel industry to undertake contracts, the Bureau's program of facilities expansion was timely enough to avoid an ever threatening bottleneck.

With adequate facilities under construction, the Bureau was able to undertake a new program for production and procurement to maintain a fleet at war, replace and modernize old equipment, and keep pace with new construction schedules. This new problem was immensely eased by the complete internal reorganization accomplished 10 months before the outbreak of the war. For nearly a century the Bureau had operated under a vertical organization, which in early 1941 included 17 independent sections with only a nominal division organization. With the exception of one for administration and another for design, the sections were each devoted to a particular type of ordnance. For instance, the gun section was theoretically responsible for every phase of gun activity from initial development through ultimate scrapping. Each section was considered coequal, with the heads reporting directly to the Chief of the Bureau or his assistant, and coordination depended upon the direction of the Chief or the personal cooperation of the officers in the various sections. For many years, even during World War I, the organization worked well. Concentration and

Adm. W. H. P. Blandy, as Commander in Chief, Atlantic Fleet, headed the Bureau of Ordnance as a rear admiral from February 1941 to December 1943.

Chapter 6

TORPEDOES

"IF you want to fill 'em with air, bomb 'em; if you want to fill 'em with water, torpedo 'em." Such was the succinct appraisal of the torpedo made by a veteran pilot. And the superiority he recognized over bombs could be extended to cover the wide range of projectiles, for no weapon in the war proved half as destructive to enemy capital ships as the "fish." Yet for every complimentary comment, a host of damning ones echoed back from the war zones. United States torpedoes were variously described as running too deep, not exploding, exploding too soon, or not packing enough punch when they did explode.

The indictment unfolded point by point during the first 2 years of war. As each defect was exposed, the morale of the submariners who risked their lives to take the war to the enemy suffered, the enemy was given further respite from the full potential of torpedo warfare, and the Bureau of Ordnance was faced with the task of uncovering and correcting the mistakes of peacetime. Considering the extreme complexity of torpedoes, the job would have been a challenge under almost any circumstances, and the problem was compounded by the Bureau's reluctance to accept the fleet evaluation of its weapon. This reluctance was born not of any petty attempt to cover past errors, but from misplaced confidence in its own past work. And that confidence was occasionally bolstered even when the inadequacies of torpedoes were being exposed, because the evidence that came in from fleet commands was often contradictory.

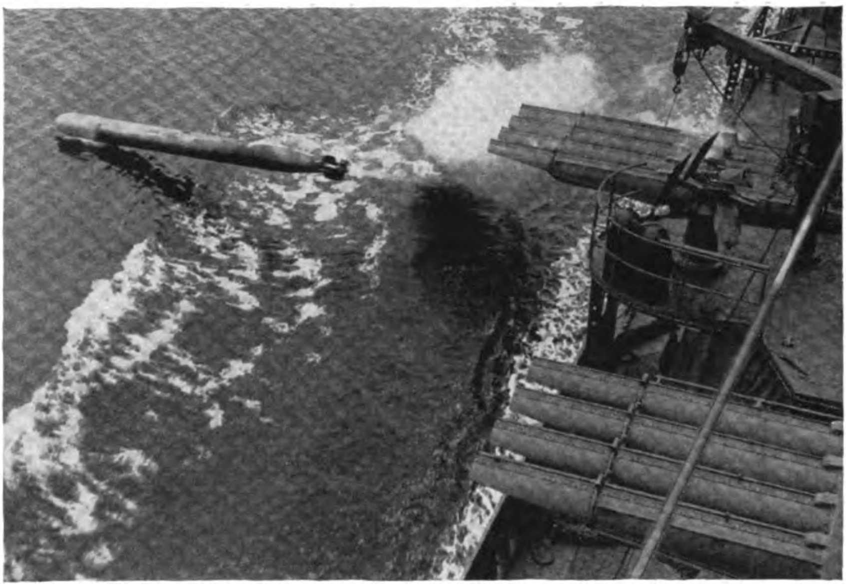
When torpedoes were finally improved to the point where they became reliable weapons, the reasons underlying their earlier failure were apparent. During the interwar period when time was available for research, the Bureau's approach to the torpedo problem was not properly scientific. Evaluation was almost invariably inadequate and tests were unrealistic. Economy was properly a goal, but improperly applied. Security, a necessary concern of the armed forces, became such a fetish that measures designed to protect a device from enemy eyes actually hid its defects from those who made the regulations. Ironically, some of those defects were

already known to the foreign powers who later became our allies or enemies.

Production planning in the prewar years was also faulty. Torpedoes were designed for meticulous, small-scale manufacture. When military requirements demanded that they be supplied in large numbers, a series of new problems were exposed. There were simply no realistic plans available for providing the weapons in adequate quantity. The old ordnance motto, "The more we sweat in peace, the less we bleed in war," hung dutifully in many an office and shop, but the sweat was apparently as misplaced as the general confidence in the Navy's torpedoes. The ebbing of that confidence became a vital part of torpedo history. Brutal facts and technical details were no more significant than the attitudes of those who interpreted the facts and directed the technical developments.

In 1937, when the international crisis began to deepen in both Europe and Asia, the United States had 3 general torpedo types ready for combat service—1 for submarines, 1 for surface vessels, and 1 for aircraft. All shared certain common characteristics. After being dropped from a plane or ejected from tubes by compressed air or gaseous pressure, steam for their propulsion turbines was generated by forcing a spray of water through an alcohol torch. An excess of combustion air at high pressure augmented the steam supply. Steering was controlled gyroscopically, while a pendulum-hydrostat device, regulated by water pressure, governed depth control. Although their military characteristics differed widely, each type carried roughly a quarter ton charge of explosive which could be detonated by contact or magnetic influence. Obsolescent torpedoes—Marks 7, 9, 11, and 12—were added to the stockpile through conversion and modification in 1941 and 1942, when quantity rather than quality seemed the vital problem, but the burden of torpedo warfare had to be borne by the latest models in stock and production on December 7, 1941—the Marks 8, 10, 13, 14, and 15.

Surface ships were normally equipped with the Mark 15 type torpedo, a rugged and relatively reliable performer. Based on a design originally conceived in 1918 for the Mark 11, this $10,000 weapon was characterized by a unique three-speed feature designed to give it the greatest possible adaptability to various tactical situations. External speed settings gave a speed/range choice of 28 knots to 15,000 yards, 34 knots to 10,000 yards, or 46 knots to 6000 yards. In addition to the obvious tactical advantages of so flexible a weapon, designers had been influenced by the Bureau's desire to concentrate in one model the military features of torpedoes re-



Torpedo Mark 15 was a rugged and relatively reliable performer.

quired for cruisers, destroyers, and submarines. This goal, while logistically attractive, proved unobtainable; long range, a must for destroyers, required a weight and length prohibitive for submarines and aircraft. Nonetheless, the ideal was most nearly achieved in the Mark 15 type.

Most of the kinks inevitable to torpedoes deprived of actual combat trials had been ironed out of the Mark 15 before the United States entered World War II. Early models were built with a new type, top-bearing turbine mounting, but recurrent lubrication difficulties induced the Bureau to revert to the older, overhung type. This conversion was completed before declaration of the national emergency, so surface vessels had a promising weapon when war finally broke. Even the supply problem—one of the greatest the Bureau faced after wartime expenditures dwarfed peacetime production plans for war—became critical for the Mark 15 less quickly than for the other standard types. Pressure on existing stock was relieved by the tendency to reduce surface ship concentration on torpedo warfare. Also, Mark 8 torpedoes, an earlier low-speed type, were issued to cruisers, "four-piper" destroyers and, later, to destroyer escorts. The increasing emphasis on planes had the same effect, since the demand for more antiaircraft guns reduced the deck space available for torpedo tubes. Thus, at the outset of the war, the Bureau was less concerned about the supply of de-

stroyer torpedoes than about meeting requirements for aircraft and submarines.

Even before the end of 1942, however, that relatively happy picture had changed. Torpedo tubes were installed on destroyer escorts, and overall expenditures in the first year of war exceeded expectations. Looking ahead, the Bureau anticipated a shortage in the fleet by the following spring. Some relief was achieved by conversion work on Torpedoes Mark 11 and 12, but nothing short of new production schedules gave adequate promise of meeting requirements. The whole problem was further complicated by existing priorities on submarine and aircraft torpedoes, which left scanty facilities for an expansion of the Mark 15 production schedule. Retooling of plants engaged in other work threatened prohibitive delays which, always costly, were especially undesirable while the war picture was still changing. Meshing the new problem into the overall procurement pattern, the Bureau chose the new Naval Ordnance Plant at Forest Park, Ill., as the principal producer.

Difficulty followed difficulty in rapid succession. Spring brought no new torpedoes. When the first Forest Park Mark 15 was finally proved in the early summer of 1943, defects were numerous and depth failure consistent. In common with most torpedoes, the Mark 15 had earlier shown a deep running tendency, but now the behavior was accentuated. Even when the problems resulting from placing a new plant into production on an emergency basis were ironed out, manufacture stayed in low gear. This stemmed largely from previous acceptance of the notion that torpedoes could be built only by craftsmen who knew the proper trade secrets. These secrets, instead of being properly committed to writing on drawings and in specifications, were largely matters of memory or notes in some foreman's little black book at the Newport Station.

Until all production information was drawn together in a usable form, manufacturers were severely handicapped. By fall, 1943, the problem had grown to urgent proportions. Germany still possessed powerful surface units against which convoys needed torpedo carrying escorts as protection, so the Bureau reluctantly made a major shift in its procurement schedules. The experienced Newport Station was switched from work on aircraft torpedoes to production of the Mark 15. By the middle of 1944 this particular crisis was over, partly because of the combined output of the two stations and partly because the gradual disappearance of suitable targets led to further armament changes in the fleet. Torpedo tubes were removed from many destroyer escorts, light

cruisers, and some destroyers. On others, the tube load was reduced. By the end of the year, Mark 15 torpedoes were in excess supply. Within a month, however, the Bureau was aware that quantity had been gained at the expense of quality. Defects common to rapid and inexperienced production of a complex mechanism had been multiplied by shortages of critical materials. Because cadmium was in short supply, the interiors of air flask sections and water compartments of the Forest Park torpedoes were plated with zinc. Almost immediately, zinc oxide deposits began to clog water strainers, causing a flood of complaints to reach the Bureau. Erratic runs and engine failures were frequent.

In an attempt to correct this situation the Bureau of Ordnance sponsored experiments to determine the feasibility of using the "Cronak" process to inhibit the troublesome zinc corrosion. Although the process had been designed for that specific purpose, the experiments on the Mark 15 torpedoes were a failure, probably because the zinc had started to corrode before the inhibitor was applied. An interim treatment using a sodium chlorate solution in the water compartments proved successful as a temporary expedient, but extensive reworking was inevitable. Even though the war was in a critical stage, the Bureau had to recall torpedoes and authorize new facilities to strip the offending zinc and replate the flask and water compartments with cadmium or coat them with baked Heresite, a new phenolic resin product.

Once that was accomplished, destroyers were again in possession of an effective torpedo. Of approximately 11,000 Mark 15 torpedoes procured during the war, in keeping with varying armament requirements and shipbuilding schedules, almost 9000 were still in store when Japan capitulated. Production was necessarily geared to stated requirements, but the surplus vindicated the original Bureau assumption that war tactics would reduce the use of torpedoes by surface vessels. Lacking both concealment and speed, as compared with submarines and planes, these ships could rarely maneuver into a position for effective torpedo firing.

As expected, submarines were the best and most effective customers for torpedoes. During the course of the war some 5 million tons of enemy shipping were sunk and another 2½ million tons damaged by the submarines' principal weapon. Although some newer torpedoes were introduced toward the end of the war and some older models converted at the start, United States submarines fought and won their war with 3 torpedoes—the Marks 10, 14, and 18. But if submariners were the best customers, they were by all odds the most critical. Maneuvering for a war shot

placed men and machine in such jeopardy that infallible performance seemed a justifiable demand. When far from infallible performance was achieved, protests flowed in to the Bureau. When performance fell short of even the normal expectations for so complex a weapon, the criticism became a howl of protest with a paradoxical dual effect: Torpedo development was stimulated, yet made increasingly difficult. Once suspicion was engendered, improving a weapon was hardly less difficult than selling the new modification.

Of the three principal torpedo types used by submarines, the Mark 10 was the oldest, the best understood, the least used, and therefore the least criticized. About 30 years old at the start of the war, this torpedo was built for the R and S Class vessels that could not fire the longer Mark 14 type. Doubling as a reserve weapon for PT boats and for new fleet-type submarines, the Mark 10 was a 2215 pound, 21-inch torpedo with steam turbines capable of driving it 3500 yards at 36 knots. The Mark 3 exploder, a simple contact device, was used to detonate the warhead of 497 pounds of TNT or, later, of 485 pounds of Torpex. As a product of the depression, tests on the Mark 10 had been mainly characterized by economy. Within a month after the Pearl Harbor attack, the ultimate cost of unrealistic torpedo testing became evident. For the Mark 10 the price was a common one—deep running.

Without waiting for basic corrections of the fault, the Bureau of Ordnance informed the fleet in January 1942, that the type would run 4 feet deeper than set. No repercussions resulted. Very few warshots had been made with the Mark 10 before the Bureau instructions arrived in the Pacific, and a predictable error posed no problem to submarines. By the summer of 1943, when supply was no longer the pressing problem it had once been, the Bureau of Ordnance abandoned production of the Mark 10. To take its place a shorter modification of the Mark 14 was built for use on the R and S Class submarines. Increased interchangeability of parts and the abandonment of an unnecessary type—always Ordnance goals—justified the move. Earlier in the war any such added emphasis on the Mark 14 type would have been unpopular with the fleet, for this was the torpedo around which the great debate was centered.

At the outbreak of the war the Mark 14 was the most recent type placed in quantity production. Longer, faster, heavier, and longer ranged than the Mark 10, the Mark 14 approached the multispeed feature of the destroyer torpedo. Submariners could choose between two speed settings: high, 46 knots to 4500 yards, or low,

31.5 knots to 9000 yards. The low speed setting was so seldom used early in the war that a new torpedo, the Mark 23—essentially a Mark 14 with the lower power setting eliminated—was introduced as a substitute.

Good results were expected of the Mark 14. Although never tested in combat before the attack on Pearl Harbor, extensive proving at the Newport range indicated the torpedo's readiness for war. Until the spring of 1945, supply was a problem, but during the first two years it seemed almost insignificant beside the nightmare of improving a faulty weapon. A long succession of complaints poured in from submarine commands: The torpedo ran deep, the detonators were faulty, the arming distance was too great, the magnetic exploder was undependable, the anticountermining device was improperly designed, the firing spring was too weak, and, even when the torpedo exploded properly, it lacked the punch submariners desired. The situation would have been bad if discovery of all of the defects at the outset had required a redesign of the weapon; what was worse, however, was the diabolical way in which each defect concealed another. No sooner was one kink ironed out before another was exposed. Correction had to be gradual and at the expense of the fleet's confidence in the weapon supplied them. The whole situation was aggravated by differing concepts of what the torpedo was and should be. Even while it worked night and day to improve the weapon, even when it acknowledged the defects pointed out by the service, the Bureau of Ordnance felt that the Mark 14 was a good torpedo. Perfection was desired, but not expected. The fleet, on the other hand, felt entitled to an infallible weapon and remained critical of anything less.

The first major defect exposed by service use was the common one of deep running, Several factors contributed to that tendency. Torpedo depth control was governed by a device known as the Uhlan gear. Before its introduction, pendulum control had been paramount; no greater angle of dive or climb than 1° was permitted by the depth mechanism. With the adoption of the Uhlan gear, the hydrostatic element became paramount, making recovery in depth rapid, almost immediate, in marked contrast to the older system that permitted torpedos to run most of their range before recovering from the initial dive. The new device was admirable, but its good possibilities were at first canceled by an error in its placement in the torpedo. Formerly, the hydrostat which controlled depth had been carried well forward on the torpedo. With the introduction of the new mechanism it was decided to remove

the depth control mechanism aft, nearer the rudders it controlled and in an area where space requirements were less critical. The new mounting was also at a slight angle to the torpedo's axis, and for reasons not suspected, prevented the device from reacting properly to depth. Still another reason for poor depth performance was overloading the head of the torpedo. In answer to demands for additional "punch," the Bureau made successive additions to the warhead, increasing the explosive charge from 507 pounds of TNT to 668 pounds of Torpex. Each change, no matter how small or desirable, altered the running characteristics of the torpedo. The center of gravity shifted and new stresses were placed on the head.

A certain variation of performance among individual torpedoes was expected, and for that reason each torpedo sent to service was accompanied by a detailed log showing the ranging results of that particular weapon. Guided by that information, a torpedo officer could presumably calculate the proper settings. But consistent depth failures did not show up in the logs because the depth and roll recorder, the instrument designed to collect the data, was improperly used. The device recorded depth as a function of pressure, but the configuration of the torpedo at the point of water intake to the instrument exposed it to a pressure differing from that at the true running depth of the torpedo. Both the depth mechanism and the measuring device checked each other, but both were improperly placed. Before the introduction of sonic instruments at the proving range, the actual performance of a recorder in a running torpedo could only be checked by firing the weapon through one or more nets. Such tests were occasionally made, but the procedure was arduous, costly, and undependable. Nets failed to hang straight down in the least current and the distance from the top of the net to any given strand was not the same in the water as it was when the net was hung in the air or laid out on the ground. Thus, when contradictory evidence was gathered from recorders and net firings, the results of the latter were discounted.

Still another reason for the failure to expose deep running was the disparity between combat and proving conditions. In order to pack the most goods into the smallest package, conventional torpedoes were built with a considerable negative buoyancy. But that characteristic had to be altered for test shots so that the weapons could be quickly and cheaply recovered. Exercise heads, filled with some liquid that could be expelled at the end of a run, were fitted to each torpedo to provide buoyancy. For years the

exercise head closely approximated the warhead which it temporarily replaced, but that condition was altered when the Bureau began increasing the explosive charges. Testing conditions became more and more unrealistic, obscuring the effect of the heavier warhead on depth performance. Occasional shots were made with dud loaded warheads, but they were too infrequent to expose the inadequacy of the exercise heads. Thus, despite extensive proving, depth failures did not appear in the logs upon which torpedo officers depended.

Even during fleet exercises the error in depth could not be detected. To prevent impact damage to the weapon and target ship, practice shots were always set to run under the target. Concern over saving the torpedoes was so great that no one stopped to wonder just how far under the target the torpedoes were running. The Bureau of Ordnance depended on Newport to check actual depth performance, and Newport depended on the misused depth and roll recorder to collect that data. The unreliability of the recording instrument remained hidden for years—consistently erring in exactly the same manner as the control in the torpedoes. No one at Newport guessed that a defect was hidden by the very instrument designed to expose it.

The fleet possessed less blind confidence in the Station's procedures, however, and even though their normal exercises failed to expose the deep running tendency, there were warning exceptions. In 1938, for example, a destroyer command engaging in battle practice off Coronado, Calif., found that half its torpedoes failed to function properly. When many surfaced in 90 feet of water with the exercise heads covered with mud, deep running was obvious. A heated exchange of letters followed, and the Bureau dispatched a torpedo officer to the scene to investigate the failures. Unfortunately for the future, evidence of poor maintenance or rough handling impressed the Bureau representative more than the bottom sand which constituted the destroyer command's exhibit A. The incident failed to shake official faith in the procedures of the Naval Torpedo Station. For three more years the inadequacies of torpedoes were obscured by misplaced faith in faulty procedures and an inaccurate recording device.

War shots, however, were quick to expose discrepancies between logged characteristics and actual performance. A few perfect setups that produced no hits could be labeled erratic runs or blamed on poor fire control, but repeated offenses aroused grave suspicion. Acting on the complaints of his skippers, the Commander in Chief, United States Fleet, ordered net firings made during the summer

of 1942. The tests confirmed the submariners' conviction. When fired from submerged tubes, Torpedoes Mark 14 ran an average of 10 feet deeper than set. Although the Bureau still did not know why the erratic depth performance resulted, it did know of the existence and amount of the error. On August 1, 1942, the services were officially informed of the 10-foot error. Until the Bureau rooted out the causes of the failure, submariners got good depth performance by allowing for the known error when making the setting for each shot.

Although the Bureau of Ordnance and the Newport Station for which it was responsible were slow to recognize, admit, and correct the erratic depth performance of the Mark 14, their feeling that the torpedo was basically good was substantiated. Even before the serious depth difficulties were corrected, it was producing better results than either the English or the Germans got from less criticized weapons. But a good torpedo was small comfort unless its potentialities could be realized, and the improved Mark 14 remained an unreliable weapon. Elimination of the deep running tendency increased the percentage of known hits and exposed the fact that even when it struck the target the torpedo did not necessarily explode.

The villian at this point turned out to be the long secret Magnetic Exploder Mark 6. Its poor performance was obscured as

Torpedo Mark 14 was a source of much grief—for United States submarine skippers and many an enemy crew.

long as torpedoes ran so far under a target that the exploder could not be expected to perform, but by the early fall of 1942 some of its weaknesses began to become apparent. Direct hits were often duds; on perhaps 10 percent of the early war shots premature explosions made hits impossible. Both duds and prematures attracted the attention of the enemy to the attacking submarine and added hazards to its operations. In effect on the morale of submarine crews and the relations between the fleet and the Bureau of Ordnance, these exploder defects proved even more serious than the deep running tendency just eliminated. This was unexpected. The Bureau was reluctant to believe that the secret weapon long regarded as one of our greatest assets should turn out to be a liability. After considering and experimenting with several different types of exploders, the Bureau had regarded the Mark 6 as the ultimate in development.

Early United States torpedoes employed the simple contact exploder developed for the Whitehead models, but shortly before World War I the Bureau of Ordnance developed a more complex and advanced type operating on the "ball" or inertia principle. During and after the war, successive changes further improved the device. The Mark 3, for instance, employed an arming impeller which projected from the side rather than the nose of the warhead, permitting the exploder to be placed near the center of a long explosive charge. Increased effectiveness was also assured by the addition of anticircular-run and anticountermining mechanisms.

Meanwhile, however, German developments were leading the Bureau to adopt a new and secret trend in exploder development. Before the end of World War I, the Kaiser's Navy produced magnetic exploders for use in mine warfare. The possibility of adapting the same principle to torpedo exploders seemed to promise a great boost in the potential of torpedoes. With detonation produced by magnetic influence rather than by impact, a hit would not even be required. For all practical purposes, the size of the target ship was magnified. Better still, torpedoes could be exploded under the bottom of ships where no armor protected the vulnerable hull. While the point was always disputed, prevailing opinion in the Bureau considered such an explosion more desirable than a direct hit against the side of an enemy vessel.

So attractive was the goal that in the immediate postwar years the Bureau experimented with a variety of ways to produce an influence explosion. Sound controlled torpedoes, a water kite above a deep running torpedo, and the creation around a torpedo

of an electric-magnetic field that would be disturbed by the entrance of a metallic body such as a ship were all tried, then abandoned. But the idea of using magnetic influence opened a new field and on June 30, 1922, the Bureau of Ordnance instituted at the Newport Station the "G–53 Project" that eventually produced the Mark 6 exploder. The project seemed especially timely since that same year witnessed the adoption by most nations of new antitorpedo structural protection for their first line fighting vessels. More than ever, underbottom explosions seemed desirable, and the G–53 Project was allowed to suffer less from budget restrictions than the testing and development of other weapons in the arsenal of underwater ordnance.

With the help of the General Electric Co., which produced the generator and developed thyratron electronic tubes for the project, Newport had the Mark 6 ready for testing by 1926. Although the idea of employing magnetism was first crystallized by Germany, the United States' exploder represented a new line of development. The swinging of a compass needle when approached by the magnetic mass of a ship activated the German device; our mechanism utilized the variations in the intensity and direction of the earth's magnetic field adjacent to the hull of a vessel to actuate the mechanical pistol that set off the explosive charge. On May 8, 1926, 4 years of work were crowned by success. A submarine hulk was towed to sea, then sunk by the first shot of a torpedo equipped with the new magnetic influence exploder.

The occasion was memorable: It marked the greatest stride yet taken in exploder development; on the debit side, it prematurely closed realistic experimentation with the new mechanism. Never again during the 19 years of prewar exploder development was a destructive test made with a torpedo equipped with a magnetic influence exploder. How ironic that success should have been its own deterrent! Testing continued, of course, and a conscientious effort was made to duplicate service conditions, but several factors fell short of realism. Most of the tests were conducted in the same magnetic latitude, and no amount of effort could exactly duplicate the variables—age, storage conditions, handling, and targets—later encountered by the fleet. Even more important, neither laboratory nor range tests indicated the kind of performance the service would require.

Meanwhile, the fleet for which the weapon was designed did not even know of its existence. The Bureau reasoned that if secrecy were not maintained the effectiveness of the weapon might

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be destroyed through enemy countermeasures and new hull designs. In this case extreme caution was ill-advised. England, Germany, and Italy all had magnetic exploders of their own before the outbreak of World War II; Japan lacked one only because she considered them impracticable and, though evidence is inconclusive, possibly knew enough about the Mark 6 to overdegauss her ships as a countermeasure. While foreign nations were developing their own varieties of influence exploders, the Bureau of Ordnance produced the Mark 5, a dummy for the Mark 6. Identical to the latter except for the secret feature, the Mark 5 was issued with each torpedo that would later receive the influence exploder. As an added precaution to guard secrecy, even the men working on the mechanism were allowed only the vaguest idea about their project. A selected group from the research section at Newport did all of the assembling and testing in rigidly maintained seclusion.

Their testing was inadequate. Evidence of that fact came in 1939, when Newport reported to the Bureau that the exploder was giving unexplained prematures. Admiral Furlong arranged for a physicist to visit the station and investigate the failures. For approximately a week, the scientist and his assistants worked with the device. Four sources of prematures were uncovered. Even more significant, the investigator reported to the Bureau that the responsible engineers at Newport were not employing proper tests on the Mark 6. Corrective steps were ordered by the Chief, but subsequent events proved that the remedial action, like the original tests, was inadequate. Exaggerated security measures obscured a multitude of sins.

Less than a year before the attack on Pearl Harbor, the policy of extreme secrecy was relaxed. Realizing that scientific ideas are an international currency, Admiral Blandy, Chief of the Bureau, decided that familiarity with the weapon within the fleet would be more valuable than hopeful refrigeration of the idea within the Bureau. During the summer of 1941 his ideas were implemented by the inauguration of a training program at Newport for selected officers, and by a limited issue of the exploder to the fleet. The classification remained secret, but the circle of the initiated grew more rapidly. Unfortunately, the move came too late to permit service testing and criticism of the exploder, and its classification remained high for so long that the men who actually used and maintained the device were barely familiar with it. The speed with which the fleet relayed its reaction to the Bureau once war made the weapon familiar is an indication of the benefits that might have been gained by an earlier introduction of the exploder. More-

over, the procedure of firing under a target during practice—inadequate as it was for exposing depth failures—would have afforded a large volume of tests for the Mark 6.

Even the deep running tendencies of the Marks 14 and 15 torpedoes were aggravated by the exploder. Early in 1942 the Bureau of Ordnance suggested that torpedoes equipped with the magnetic exploder be set to run ten feet beneath the enemy's keel. When added to the 10-foot error inherent in the torpedoes themselves, that meant a miss of such wide proportions that even an influence exploder could not always produce an explosion. Even when it did, an explosion so far from the hull was seldom effective. On the other hand, the errors could cancel themselves out to the disaster of the enemy. Many shots planned for impact against the side of a ship missed because of deep running, yet damaged the enemy due to the influence feature of the Mark 6. For other exploder-induced errors there was no such compensation, however, and two new types of failure—prematures and duds—were added to the problems that plagued submariners. Nor was that all. In addition to charges of functional failure, the Mark 6 was criticized for an inadequate physical design that permitted flooding of the exploder cavity in action-ready torpedoes and for a complexity that required excessive "babying" and long hours of testing and overhaul.

Behind the failure of the Mark 6 exploder to live up to Bureau expectations were some of the same factors that caused torpedoes to fall short of the efficiency the laboratory tests predicted for them. Undue secrecy and unrealistic testing were hardly more culpable than the extreme complexity that defied perfection. TNT being hard to detonate, even a simple exploder required mechanisms that could set off the required detonation wave. In the Mark 6 a series of three explosions were induced: First, the firing pin struck the primer cap, which set off a detonator in the base of the booster charge; then the explosion of the booster climaxed the detonation wave by setting off the torpedo warhead. Unlike other exploders, the Mark 6 contained the special feature that could initiate an explosion by sensitivity to the magnetic influence of an enemy vessel.

When the torpedo was ejected, its rush through the water spun a small turbine which, in turn, operated a gear train that pushed the detonator into the booster cavity. The 450 yards required for that operation afforded security for the firing submarine and gave the torpedo time to find its course and settle down on a normal run. During the same period, vacuum tubes within the 91

pounds of exploder mechanism warmed up and readied the influence features for operation. As soon as the torpedo entered the magnetic field created by the enemy hull, the electromotive force generated in the exploder's induction coils began to change. That change, amplified by vacuum tubes, was harnessed to release the firing pin which initiated the detonation wave at the proper theoretical moment for optimum results. Where contact rather than magnetism was to induce the explosion, impact dislodged an inertia element which released the firing pin. An anticountermining device, later proved defective and removed, added to the general complexity that led Vice Admiral Lockwood to call the exploder a "Rube Goldberg" device with 5 or 6 things that might go wrong.

Aside from the discovery in the early months of the war that the anticountermining mechanism might prevent the proper functioning of the exploder, the first indication that the Mark 6 was responsible for erratic torpedo behavior came in August 1942, when correction of deep running exposed the tendency of premature explosions. There were two reasons for the disclosure then: while torpedoes were running far under the target, the defect remained hidden; when the error was corrected so that torpedoes were set for shallower depths, one result was that the weapons entered the enemy ship's magnetic field some distance from its hull. Unless perfectly adjusted, the exploder might act promptly, causing a premature by as much as 50 feet. The exact extent of the failure was impossible to determine. Observed through a periscope, a premature explosion might well appear to be a hit, yet submariners were convinced that some 10 percent of the torpedoes they fired were prematures. The Bureau, analyzing combat reports as they were received, concluded that prematures did not exceed 2 percent of the total shots fired. Whatever the truth, ill feeling was the result. In the fleet, a distrust of their torpedoes spread; in the Bureau, remedial actions were taken.

In attempting to pin down the source of the failures, the Bureau first concluded that prematures were usually due to faulty brush adjustment on the generator and to warping of generator brush discs. Before the end of 1942, Newport was instructed to redesign the exploder, using batteries instead of a generator as the source of power. Meanwhile, experiments convinced the Bureau that the relatively short arming distance increased the tendency to premature, and it suggested to the forces afloat that the effectiveness of the Mark 6 could be increased if the arming distance was raised from 450 to 700 yards. In the Pacific, the principal arena

of torpedo warfare, the suggestion was not considered acceptable. Admirals King and Lockwood, voicing an opinion already prevalent among submariners under their commands, concurred in a recommendation that the Exploder Mark 6 be replaced by a simple, reliable exploder. Further suggestions by the Bureau, such as new instructions on depth settings for optimum results and information on the variations in performance to be expected in different magnetic latitudes, did not materially alter the situation. By July 1943, inactivation of the influence feature became a popular procedure for dealing with the Exploder Mark 6. On July 24, the practice was officially sanctioned when Admiral Nimitz, Commander in Chief, Pacific Fleet, ordered his submarine and destroyer commands to inactivate the magnetic device on all torpedoes.

Only South West Pacific submarines continued using the feature. The submarine commander there, Rear Admiral Christie, an experienced torpedo design officer, was the chief advocate of the Mark 6 in the Pacific. His defense and continued use of the weapon stemmed from no feeling of satisfaction with the mechanism, but from fear that if his command joined those to the north in inactivation, the magnetic exploder, with all its potentialities, might become a dead issue for the war. Until improvements were made, the Admiral trusted in careful use and maintenance of the device to produce satisfactory results. By the spring of 1944, however, his submarines were instructed to follow the lead of those based at Pearl Harbor in abandoning the use of the magnetic feature. The Southern Hemisphere was hardly suitable for the magnetic exploder; prematures appeared too common to justify continued use of the influence feature.

In the face of a widespread refusal to use the weapon that the Bureau had considered one of its greatest assets, efforts to improve and restore confidence in the exploder were redoubled. Admiral Blandy had already indicated the direction of such efforts with a biting directive on torpedo policy. Addressing the Newport Torpedo Station some months earlier, the Chief of the Bureau wrote:

"Even with the relatively meager funds available in time of peace, much of the work now being done after more than a year and a half of war, could and should have been accomplished years ago. . . . That the work was not accomplished during peace or earlier during this war, or, so far as the Bureau's records disclose, that no one either in the Bureau or at Newport apparently questioned the inadequacy of the design without such tests, shows a lack of practical appreciation of the problems involved which is

incompatible with the Bureau's high standards, and reflects discredit upon both the Bureau of Ordnance and the Naval Torpedo Station, Newport. The Chief of the Bureau therefore directs that as a matter of permanent policy, no service torpedo device ever be adopted as standard until it has been tested under conditions simulating as nearly as possible those which will be encountered in battle."

Admitting the failure of the Mark 6, as such, the Bureau retained faith in the principles upon which it was based. Even when no Pacific forces were using the influence feature of the exploder, the Bureau and Newport proceeded to produce successive modifications, so that a reliable weapon would be ready if a change of heart were experienced in the fleet. To supplement the efforts of the Torpedo Station, Admiral Blandy arranged developmental contracts with four additional research activities. By the end of the war two new influence exploders were considered ready for fleet trial.

Meanwhile, the Bureau argued the case for influence exploders before the fleet, pointing out that it could produce hits where incorrect settings would normally result in misses. In order to give the forces afloat a more realistic picture of what could be expected of the exploder, the Bureau distributed a new formula to guide its use, based on magnetic latitude, target course, degaussing conditions, target beam and draft, and the depth setting of the torpedo. All was to no avail. Modifications of the Mark 6, available by the fall of 1943, were regarded with suspicion afloat. Between the late summer of 1943 and the spring of 1944, the exploder was not receiving a fair trial in the Pacific; in the northern latitudes for which it was designed, the device was not used. After April 1944, it received no service tests at all. Although the Bureau soon corrected faulty design in the electrical feature of the exploder and continued to send improved stock to the fleet, the chances of getting the weapon reaccepted grew dimmer. By the late summer of 1943, complaints about duds joined those concerning prematures; when inactivation stopped prematures altogether, the full extent of outright duds was exposed. In many respects the ensuing problems were more damaging to morale and relations between the fleet and the Bureau than either the deep running or premature failures.

Almost from the beginning of the war complaints about duds had been interspersed with other torpedo criticism. Inactivation of the anticountermining device improved the situation somewhat, but after the influence feature of the Mark 6 was inactivated and the contact mechanism subjected to more severe use, the presence

of additional kinks became obvious. The origin of the problem lay back in the prewar years when inadequate testing hid the fact that exploder design was not keeping pace with changes in torpedo characteristics. In early type exploders the firing pin moved along the axis of the warhead, which meant that reliability was in direct ratio to the force of impact. In the Mark 6, however, design changes altered the relation between torpedo speed and exploder performance; the firing pin, actuated by a spring, moved vertically, or at right angles to the normal axis of the torpedo. The result was that a severe impact often produced sufficient friction against the leading edge of the pin to prevent its striking the cap quickly enough or with enough force to produce detonation. In other cases, the shock so deformed or displaced the guides that movement of the firing pin was restricted. Newport had not been blind to the problems posed by the new design. In the late 1930's the Station conducted tests of the device, then strengthened the spring to help overcome the increased friction. The expedient worked, but subsequent increases in torpedo speeds soon negated the improvement—a result that remained hidden until wartime use compensated for the inadequate peacetime testing.

Complaints from the fleet concerning duds were difficult to evaluate. Throughout the controversy over the adequacy of United States torpedoes and exploders, performance remained statistically good. In mid-1943, for instance, a report from ComSubPac showed only nine failures of contact exploders out of more than 1800 torpedoes fired by the submarines operating out of Pearl Harbor. During the same period, over 600 hits were reported. Neither the British, Germans, nor Japanese could boast of such an achievement. Of course the United States couldn't either, since the official reports did not jibe with the truth, but the report was made to, not by, the Bureau of Ordnance. Moreover, variations within our own forces suggested that human failures were being tabulated in the mechanical ledger. Some submarine skippers reported better than 60 percent hits, while others using the same equipment in the same theater registered hits for less than 10 percent of the shots fired. A further investigation of combat reports showed that 40 percent of all submarine attacks were made at periscope depth between the hours of 1900 and 0600, when conditions were not favorable for the precise estimation of enemy course and speed or of the results of shots fired.

Backed almost continually by favorable statistics, the Bureau's confidence in its weapons was slow to follow the downward curve of fleet estimation. Unfortunately, both torpedo performance and

the Bureau's attitude were exaggerated over coffee cups in Pacific wardrooms; among some submarine captains the feeling was soon prevalent that the Bureau definition of a dud was "a skipper's alibi to explain his miss." The attitude was the normal result of severe working conditions, but it was only partly justified by facts. Before the end of 1942, the Bureau recommended use of a stronger spring to actuate the firing pin for contact settings on the Mark 6 exploder, but was too involved with deep running, prematures, and production problems to recognize the full import of reported duds.

The gravity of the dud problem was demonstrated—even exaggerated—by an event of July 24, 1943, the very day that the controversy over prematures was climaxed by the official inactivation of the magnetic exploder for Pearl Harbor based ships. The submarine *Tinosa,* operating on patrol, sighted a giant Japanese oiler. Two initial spreads crippled and made a sitting duck of one of the largest tankers afloat. In all, 15 torpedoes were fired at the oiler; 12 known hits were claimed, yet the dream target drifted on. Only the first 2 spreads produced explosions. Saving 1 torpedo for investigation, the captain took the *Tinosa* back to Pearl Harbor. Within a month, still another story was added to the lore of Bureau critics. The submarine *Haddock,* after damaging a 10,500 ton tanker with 2 hits, fired 11 more torpedoes in 3 further attacks on the same ship without getting another explosion. The combined effect of the 2 stories added renewed emphasis to the search for an improved mechanism.

When an examination of the *Tinosa's* remaining torpedo proved it to be in good condition, Admiral Lockwood started a series of tests at the Pearl Harbor base that ran concurrently with the Bureau's own investigation. In Chesapeake Bay the Bureau fired torpedoes directly at armor plates suspended in the water and found that a direct impact produced more friction than the firing pin could overcome. At Pearl Harbor the submariners made the same discovery by firing into a cliff and by dropping inert-loaded torpedo warheads on steel plates from a height of 90 feet. While both series of tests gave the same results, the solutions attempted took different directions. Pending the development of a new exploder, the Bureau favored its former expedient of strengthening the firing spring; at Pearl Harbor, the submariners got similar results by lightening the firing pin. Since the submariners were justly proud of their solution of the problem, the Bureau of Ordnance endorsed the lighter pin, combined it with a stronger spring, and ended the series of misunderstandings about the Mark 6 exploder and the Mark 14 torpedo that carried the deficient mecha-

nism. Exploder development continued, however, and before the war ended 10 modifications of the Mark 6 were completed, a new magnetic exploder, the Mark 10, was available as a replacement, and a variety of influence exploders were in advanced developmental stages.

By January 1944 torpedo performance was almost uniformly good and the most controversial chapter in the history of United States wartime torpedo development ended. A lesser argument dating from the very outbreak of the war ran on, however, as an undercurrent to the interminable problem of supplying the fleet with exactly the weapons they required. Submariners suspected that even when they got hot, straight, and normal runs from their torpedoes, the weapon lacked sufficient punch. Their suspicions were stimulated by reports that both Russia and Japan used torpedoes that carried well over half a ton of explosives more powerful than the TNT with which the United States entered the war.

On the opposite side of the controversy were a few Ordnance theorists who considered the weight and content of warheads almost irrelevant to considerations of effectiveness. At the basis of their argument was the belief that although laboratory tests of different charges might show great variations, there was very little difference in their force when used underwater. That conservative theory was bolstered by a group of damage studies made by the Bureaus of Ships and Ordnance. Joint investigations in 1940 showed that 500 pounds of TNT were enough to break down two transverse bulkheads on an enemy capital ship, and that to destroy a third bulkhead would require more TNT than could be carried by a torpedo. The quarter ton charge common to United States torpedoes appeared vindicated.

Between tests that discouraged weight changes and a theory that discounted force variations among explosives, a reluctance to tamper with existing warheads was bred in certain quarters of the Bureau. Allied arguments came from officers who believed that it made almost no difference where a ship was struck and that, so long as it sank, the time factor could be disregarded. The state of mind was dangerous and it was hard dying. As late as June 1942, Admiral Blandy pondered a General Board hearing to relegate the ideas to the scrap heap. Fortunately, the theories were not so popular that the Bureau had to take drastic action. While the truth sifted through, more realistic planners were working on the problem of developing more powerful warheads without too great a sacrifice of horsepower minutes.